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AN OPTIMIZATION MODEL FOR SCHEDULING ARMY BASE REALIGNMENT AND CLOSURE ACTIONS

by

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The United States Army is reducing and reshaping its force structure to adapt to the nation's changing defense needs and budget constraints. Along with significant personnel reductions, the Army is divesting itself of excess infrastructure through a process of Base Realignment and Closure (BRAC). A necessary step in the BRAC process is calculation of the Net Present Value (NPV) of savings associated with base realignments and closures which must be computed using the Cost of Base Realignment Actions (COBRA) model. COBRA is not an optimization model. The user must enter when specific BRAC actions will occur. This thesis develops a mixed integer linear programming model to assist The Army Basing Study (TABS), the primary analysis agency for Army BRAC issues, schedule slated BRAC actions. The model generates an optimal schedule which attains maximum potential savings within budgetary constraints. In the past, Army analysts have accomplished this scheduling within COBRA using a time consuming process with no guarantee of optimality. Using a systematic time efficient approach, the model achieved a 34% increase in savings ($223 million) over the manual schedule developed by TABS for an actual BRAC 93 scenario.

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AN OPTIMIZATION MODEL FOR SCHEDULING ARMY BASE REALIGNMENT AND CLOSURE ACTIONS

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ABSTRACT

The United States Army is reducing and reshaping its force structure to adapt to the nation's changing defense needs and budget constraints. Along with significant personnel reductions, the Army is divesting itself of excess infrastructure through a process of Base Realignment and Closure (BRAC). A necessary step in the BRAC process is calculation of the Net Present Value (NPV) of savings associated with base realignments and closures which must be computed using the Cost of Base Realignment Actions (COBRA) model. COBRA is not an optimization model. The user must enter when specific BRAC actions will occur. This thesis develops a mixed integer linear programming model to assist The Army Basing Study (TABS), the primary analysis agency for Army BRAC issues, schedule slated BRAC actions. The model generates an optimal schedule which attains maximum potential savings within budgetary constraints. In the past, Army analysts have accomplished this scheduling within COBRA using a time consuming process with no guarantee of optimality. Using a systematic time efficient approach, the model achieved a 34% increase in savings ($223 million) over the manual schedule developed by TABS for an actual BRAC 93 scenario.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The United States Army is reducing and reshaping its force structure to adapt to the nation's changing defense needs and budget constraints. Along with significant personnel reductions, the Army is divesting itself of excess infrastructure through a process of Base Realignment and Closure (BRAC). A necessary step in the BRAC process is calculation of the Net Present Value (NPV) of savings associated with base realignments and closures which must be computed using the Cost of Base Realignment Actions (COBRA) model. COBRA is not an optimization model. The user must enter when specific BRAC actions will occur. This thesis develops a mixed integer linear programming model which schedules BRAC actions in order to attain maximum total savings within budgetary constraints. The model achieved a 34% increase in savings ($223 million) over manual scheduling methods for an actual BRAC scenario.

The Army Basing Study (TABS) is responsible for the detailed analysis of all factors involved in realigning Army units and closing installations. This model was developed in response to TABS' need for a systemic approach to optimally schedule actions for slated closures and realignments. In the past, TABS has accomplished this scheduling within COBRA using a time consuming process with no guarantee of optimality. This model gives TABS a systematic time efficient approach to accomplish this scheduling in the future.

The model is designed to use data which are readily available to TABS analysts, thus avoiding any new data collection requirements. As stated earlier, the model achieved a 34% increase in savings over the manual schedule developed by TABS for an actual BRAC 93 scenario. Additionally, the model facilitates a determination as to whether or not a set of proposed closures and realignments is in fact feasible under budgetary constraints, and if not, what the budget shortfalls are. Budget sensitivity analysis also allows a determination as to how sensitive a proposed scenario is to budget reductions, allowing for rapid "what if" assessments.

The upcoming BRAC 95 round of closures represents the last legislated opportunity for the Department of Defense to confront the fiscal reality of ever decreasing defense budgets by making intelligent restructuring decisions. This model's capabilities and versatility will make it a valuable tool for all services during this process.

I. INTRODUCTION

The United States Army is reducing and reshaping its force structure to adapt to the nation's changing defense needs and budget constraints. The Army Basing Study (TABS) office is responsible for the detailed analysis of all factors involved in realigning Army units and closing installations. Once Congress has approved a set of installations for closure and realignment, all necessary actions must be scheduled over a 5-year planning period. This thesis develops a mixed integer linear program to assist military decision makers schedule closure and realignment actions to attain maximum total savings within budgetary constraints.

A. BACKGROUND

The Cold War is behind us. The Soviet Union is no longer. The major threat that drove American defense decision making for four and a half decades is gone. As a result of this profound change in our security environment and the fiscal reality of ever decreasing defense budgets, the United States Army has entered a period of significant down-sizing. Over the last three years, 180,000 soldiers have been discharged and 70,000 civilian positions in the Department of the Army (DA) have been eliminated. By 1995, planned personnel cuts will reduce the Army to its smallest size since 1939 [DA 94]. In addition to these personnel reductions, the Army is divesting itself of excess infrastructure through a process of Base Realignment and Closure (BRAC).

B. THE BRAC PROCESS

Public Law 101-510 created an independent five-year Defense Base Closure and Realignment Commission " to provide a fair process that will result in the timely closure and realignment of military installations inside the United States " [BRAC Commission 93]. Public Law 101-510, as amended, allowed the Secretary of Defense to make recommendations for base realignment and closure within the United States in 1991 and 1993, and will allow him to do so again in 1995. The BRAC Commission reviews Secretary of Defense recommendations making changes when it finds a "substantial deviation" between a recommendation and its supporting data [BRAC Commission 93]. The Commission forwards its final report to the President who must in turn accept or reject the recommendations in their entirety. The President's decision becomes final if Congress does not vote within 45 days to overturn it.

Each service has its own analytical tools and review process to evaluate installations for potential realignment or closure. For BRAC 93, the Army established TABS to make recommendations for potential base closures and realignments to the Army Chief of Staff and the Secretary of the Army. TABS employed a three-phased approach to develop its realignment and closure recommendations [DA 93].

In phase I, TABS arranged installations into 11 categories based on the primary mission and then evaluated each installation in quantitative terms to determine its relative military value within its category. Military value was based on five measures of merit: mission essentiality, mission suitability, operational efficiency, quality of life, and

expandability [DA 93]. From this analysis, TABS identified its candidates for further study.

In phase II, the study candidates were examined and alternative approaches for realignment and closure were developed. These alternatives were then subjected to a cycle of analysis based on feasibility, affordability, socioeconomic impacts, environmental impacts, and the subjective pros and cons of each alternative. TABS used these assessments to determine which recommendations to forward through the Army Chief of Staff and the Secretary of the Army to the Secretary of Defense.

Phase III began when the Secretary of the Army submitted the Army's recommendations for BRAC 93 to the Secretary of Defense. The purpose of this phase is to provide follow-on support to the Office of the Secretary of Defense (OSD), the Defense Base Closure and Realignment Commission, and Congress regarding the Army's BRAC 93 recommendations. TABS is the single point of contact for the Army Staff on matters concerning BRAC 93.

BRAC 95 will follow the same general process as BRAC 93, with minor changes in the measures of merit used to obtain the relative ranking of installations in phase I [Fletcher 93]. BRAC 95 represents the last legislated opportunity for the Army to confront the fiscal reality of ever decreasing defense budgets by making intelligent restructuring decisions. Previous rounds of Army BRAC have closed or down-sized over 20% of the Army's major installations in the US. [DA 93]. OSD guidance has targeted a further 15% reduction in capacity across all services for BRAC 95, with the goal of

achieving savings roughly equal to the total savings of all previous rounds combined [Jones 93].

C. PROBLEM DEFINITION

The overall objective of base realignment and closure is to eliminate excess capacity and avoid future costs. However, a relatively large one-time investment is required to close a base before future savings can be achieved. Lest these large one-time costs deter the Department of Defense from closing bases, Congress established the Base Closure Account to provide the initial investment. This account provides funds for military construction, relocation expenses, environmental clean-up costs, and other one-time costs that are incurred as a result of base closure. These one-time costs are justified by future potentially large recurring savings that can be achieved by closing bases [DA 93].

1. COBRA

The Cost of Base Realignment Actions (COBRA) model was the primary tool used by TABS for economic analysis during phase II of BRAC 93. COBRA is designed to estimate all the essential costs and savings associated with a proposed base closure or realignment, using data that are available to military staff organizations without extensive field studies. It is a cost-benefit analysis tool that allows evaluation of base closure alternatives using the net present value (NPV) of the proposed scenarios.

COBRA develops comparisons based on three key types of costs listed below

1. Cost of operation at the present location(s)
   - personnel costs (salaries, VHA),
   - overhead costs (BOS, RPMA, administrative support)

2. Cost of operation at the new location(s)
   - personnel costs (salaries, VHA),
   - overhead costs (BOS, RPMA, administrative support).

3. Cost of the move to the new location(s):
   - construction costs (new construction, renovations),
   - permanent change of station (PCS) costs,
   - transportation costs (freight, vehicles, special equipment),
   - personnel costs (severance pay, early retirement).

COBRA converts all base closure costs and savings into their worth at the present time, allowing valid comparisons between alternatives whose costs and savings may occur at different dates in the future.

COBRA makes two types of calculations in order to arrive at the NPV for a scenario. The Logistics Management Institute, in its first report on COBRA , describes the different calculations as follows:

> One-time costs are computed as standard charges for item-by-item actions; in doing so, the model applies Service-wide standard costs and factors to scenario specific inputs. Recurring costs and savings are computed by comparing the cost of specific services at the gaining and losing bases and predicting how much it would cost to perform the transferred services at the gaining base [Brown 89].

COBRA performs dozens of these calculations for each scenario in an effort to capture every possible significant cost and saving.

At this point it is important to clarify that COBRA is not an optimization model, nor was it intended to be. COBRA calculates the NPV for a proposed scenario based on user-defined inputs as to when specific actions will occur. For example, the user is

required to enter the personnel, equipment, and vehicles moving in each of the scenario years for each pair of bases with movements planned [Richardson 93]. Similarly, the user must specify the exact amount of all one-time costs, such as military construction, to be spent in each of the scenario years. COBRA then calculates the total expected savings of the scenario based on this specific sequence of actions. It is a purely deterministic model which produces one answer only for a given data set; it will not produce the "best" solution to any closure or realignment scenario. A different sequencing of the user-defined inputs can result in entirely different outputs.

COBRA does allow the analyst to make a relative comparison of different BRAC alternatives. However, once a set of recommendations has been approved by Congress, COBRA will not develop an optimal schedule for BRAC actions which will ensure that maximum potential savings are realized as soon as possible within the budgetary constraints of the Base Closure Account. In the past, military analysts have accomplished this scheduling using "stubby pencil" drills [Fletcher 93]. There exists a need for a systematic approach to optimally schedule actions for an approved BRAC scenario in order to begin realizing savings as soon as possible. This thesis develops a model to meet that need.

2. Modeling Approach

From the previous discussion and direction from TABS, several guiding principles were major considerations for this thesis. In particular, the model developed by this thesis meets the following goals:

1. Given a defined BRAC scenario (i.e., a complete list of gaining and losing bases), the model generates an optimal programming schedule with the objective of maximizing total savings within budgetary constraints.

2. Given several defined BRAC scenarios, the model facilitates a determination as to which scenarios are most sensitive to budget reductions, allowing for rapid "what if" assessments.

3. All model inputs are consistent with the inputs and / or outputs of the COBRA model already in use by TABS to avoid generating any new data collection requirements.

A. THESIS OUTLINE

Chapter II discusses current optimization models which are being or have been developed to address BRAC related issues and then surveys the operations research literature for work more closely related to the subject of this thesis. Chapter III provides an extensive description of the model, its assumptions, and its features. Chapter IV uses the approved BRAC 93 recommendations for Army closures and realignments as a test case for the model and provides results. A sensitivity analysis is also performed to determine how parameter changes affect model recommendations. Finally, Chapter V presents conclusions and ideas for future model enhancements.

II. RELATED RESEARCH

A. BRAC OPTIMIZATION MODELS

Military analysts dealing with BRAC issues are not foreign to the idea of using optimization techniques to assist them in their endeavors. In fact, an extensive research effort at the Naval Postgraduate School (NPS) by Professors Dell, Rosenthal and Parry has produced the Optimally Stationing Units to Bases (OSUB) model [Dell 94]. OSUB is a bi-criteria mixed integer programming model which develops realignment and closure recommendations for maneuver and training installations by maximizing military value while minimizing operating cost. The applicability of this modeling approach was demonstrated by Tarantino [1992] in a NPS master's thesis advised by Professor Dell for Army Material Command installations. Additionally, Dowty [1994] has developed a similar model to aid Navy decision makers in recommending closures and realignments for Navy Medical hospitals.

OSUB and the related models described above are examples of facility location problems and as such are not directly pertinent to the subject matter of this thesis. They do, however, show the applicability of optimization techniques to BRAC related issues and this has generated significant interest by TABS decision makers in trying to optimally schedule slated BRAC actions.

B. PERTINENT RESEARCH

The operations research literature related to capital budgeting and project scheduling is extensive. This section focuses on a cross-section of linear programming formulations and discusses their applicability and shortcomings as related to the specific problem addressed by this thesis.

Weingartner [1963] develops a systematic approach for bringing integer programming techniques to bear on certain fundamental aspects of capital budgeting with the intent of paving the way for eventual application to more concrete problems. The problem of selecting investment projects and then deciding how to fund these projects over several planning periods so as to maximize the NPV of expected returns while satisfying budget limitations is examined in great detail. However, no consideration is given to the problem whose objective is to schedule projects in order to maximize the NPV of expected returns, where all projects must be completed.

Thesen [1976] develops a heuristic algorithm for scheduling activities under resource and precedence constraints. This algorithm selects the set of feasible activities with the largest combined value of a heuristic "urgency factor" function for scheduling at a given instant of time. The heuristic function assigns overdue or prerequisite activities extremely high values while assigning other activities values which correspond to their resource utilization. A multidimensional knapsack sub-algorithm is then used to schedule these activities at given points in time. The process is repeated until all actions necessary

for project completion have been scheduled. This method does not guarantee an optimal solution and is highly dependent on the subjective choice of the urgency factors.

Donahue [1992] uses Analytical Hierarchy Process (AHP) derived benefits in a multi-objective linear goal programming model to determine which Army modernization candidates to fund in the development of the Long Range Army Material Requirements Plan. AHP basically involves the following four steps developed by Saaty [1977]:

1. Break down the decision into hierarchical levels,
2. Collect pairwise comparison data of the factors,
3. Employ the eigenvalue solution technique,
4. Aggregate the relative weights at each level.

Specifically, Donahue's model uses AHP derived benefits to determine the funding level for each program based on an aspired funding level and other competing objectives over a 15 year planning period. However, Zahedi [1986] describes AHP shortcomings which may not make it suitable for application.

Talbot [1982] develops a mixed integer linear programming model for solving a resource constrained project scheduling problem which explicitly treats cost or profit as a scheduling objective while simultaneously permitting job durations to be affected by resource allocations. Resources which may be considered include renewable resources which are limited on a period-to-period basis such as skilled labor, as well as nonrenewable resources such as money, which are consumed and constrained on both a per-period and cumulative basis. The model derives a solution which specifies when each job is to be scheduled so as to minimize both project completion time and total project cost within the framework of a resource-constrained time-cost tradeoff. This

work is the closest in terms of being directly related to the subject of this thesis. However, like all the previous models discussed in this section, this model cannot deal explicitly with all the various factors and their contingency relationships (dependencies) considered by COBRA when evaluating the potential savings of a BRAC alternative. The model developed by this thesis produces an optimal schedule of slated BRAC actions which is completely consistent with the COBRA cost estimation process.

III. A MODEL FOR SCHEDULING BRAC ACTIONS

A. INTRODUCTION TO THE MODEL

TABS will submit realignment and closure recommendations in 1995. Once these recommendations have been approved by Congress, military analysts have to schedule all actions necessary to accomplish the realignments and closures over a five year planning period within the budgetary constraints of the Base Closure Account. This chapter formulates a mixed integer linear program to generate an optimal schedule for BRAC actions which ensures that maximum potential savings are achieved as soon as possible within budgetary constraints.

As already discussed in Chapter I, COBRA is the primary tool used during phase II of the BRAC process for the economic analysis of alternative BRAC scenarios. COBRA allows the military analyst to make a relative comparison of different alternatives based on the NPV of the cash stream of anticipated savings over a 20 year period. However, the amount of savings generated during the transition period[1] of a scenario is highly dependent on when the user schedules actions which generate one-time costs during data input. COBRA has no internal mechanism to accomplish this scheduling in an optimal manner. Since COBRA plays a critical role in the development of BRAC recommendations, the model developed by this thesis must be consistent with the COBRA analysis conducted during phase II to have any validity with TABS decision makers. To that end, the optimal objective function value of this model represents the

[1] The transition period for a particular scenario starts at the beginning of year 1 and ends when all actions in connection with the transfer of activities are complete; i.e., this period generates all the one-time costs / savings for a scenario.

NPV of the savings generated by the approved BRAC scenario over the same 20 year period considered by COBRA. Additionally, all model inputs are consistent with the inputs required by COBRA. All the data necessary to run this model are available to TABS from the COBRA runs conducted during phase II of the BRAC process.

B. MODEL ASSUMPTIONS

A number of modeling issues required assumptions to facilitate the completion of this model. The decision on what simplifying assumptions to make was coordinated with TABS to ensure that the resulting model would be capable of meeting their specific needs with available data. The assumptions listed below are also consistent with the underlying assumptions of the COBRA model.

1. The transition period for a post undergoing realignment or closure will be no longer than five years. Therefore, all actions which generate one-time costs / savings must be scheduled to occur no later than year 5.

2. The average tour length for military personnel on a given installation is 26 months. Therefore, 46% of the cost to move military personnel in a given year can be considered to be due to natural rotation and not attributable to the BRAC action.

3. The discount rate used in NPV calculations is 4%, with 0% inflation.

4. Any civilian reduction-in-force actions necessitated by the closure of a post will occur in the last year of the transition period for that post.

5. Military construction paid for in year t will not be completed until year t+2. This allows for planning and construction time.

6. All civilians who elect early retirement as a result of the realignment of their post will retire in year 1 of the scenario. The annual cost of these early retirements will recur through year 3 after which the retirements will no longer be considered to be due to the BRAC action.

7. All planned / budgeted construction costs which are avoided as a result of a BRAC action will be considered as savings realized in year 1 of the scenario.

8. Recurring savings are the net savings generated each year after the transition period is complete when activities are moved from one post to another. Portions of recurring savings can be realized during transition period years based on what portion of the move is complete. Specifically, one-quarter recurrent savings are realized in transition period years when at least one-third but less than two-thirds of the move is complete, and one-half recurrent savings are realized in transition period years when at least two-thirds of the move is complete. This is a conservative estimate of the actual calculations performed by COBRA.

C. ESSENTIAL ELEMENTS OF THE MODEL

1. Indices

- **t,t'** year of the closure process (t = 1, 2, ..., 20),
- **l** post which is losing activities or functions,
- **g** post which is gaining activities or functions.

2. Data

(note: all costs are in current year dollars)

- **$CIVPCS_{lg}$** total cost to move all civilians from post l to post g,
- **$CONSAV_l$** all procurement and construction costs avoided as a direct result of realigning post l,
- **DEV_PEN** the penalty cost imposed for exceeding the budget in a given year,
- **$FREIGHT_{lg}$** total cost to pack and ship all office and special equipment from post l to post g,
- **$LAND_g$** total cost of land to be purchased at post g due to realignment,
- **$MILCON_g$** total cost of new military construction and rehabilitation required at post g due to realignment,
- **$MILPCS_{lg}$** total cost to move all military personnel from post l to post g,

- **$NEWHIRE_g$** total cost of all civilian new-hires at post g due to realignment,
- **r** the discount rate used for NPV calculations,
- **$RECSAV_l$** the steady-state recurring savings which accrue yearly as a result of the realignment of post l,
- **$RETIR_l$** total yearly cost of civilian early retirements at post l which are directly attributable to the realignment of post l.
- **REQ_g** the percentage of personnel that can move onto post g without the completion of military construction at g,
- **$SEVPAY_l$** total cost for all civilian reduction-in-force actions which are directly attributable to the realignment of post l,
- **$UNIQCOST_l$** the total of all unique costs, including environmental mitigation, which are directly attributable to the realignment of post l,
- **$WEDGE_t$** total funds available for BRAC actions in year t,
- **G** the set of all posts which are gaining activities or functions,
- **G_l** the set of all posts which are gaining activities or functions from post l,
- **L** the set of all posts which are losing activities or functions,
- **L_g** the set of all posts which are losing activities or functions to post g.

3. Variables

a. Binary

- **$DONE_{tl}$** equals one if the transition period corresponding to the realignment from post l is complete by year t; zero otherwise,
- **$1THIRD_{tl}$** equals one if at least one-third of all personnel required to move from post l have in fact moved by the end of year t; zero otherwise,
- **$2THIRD_{tl}$** equals one if at least two-thirds of all personnel required to move from post l have in fact moved by the end of year t; zero otherwise.

b. Continuous

- **$CIVMOVE_{tlg}$** portion of **$CIVPCS_{lg}$** spending in year t,
- **$CIVRIF_{tl}$** portion of **$SEVPAY_{l}$** spending in year t,
- **$CONSTR_{tg}$** portion of **$MILCON_{g}$** spending in year t,
- **DEV_{t}** an elastic variable representing the amount by which **$WEDGE_{t}$** is exceeded in year t,
- **$UNIQ_{tl}$** portion of **$UNIQCOST_{l}$** spending in year t,
- **$HIRE_{tg}$** portion of **$NEWHIRE_{g}$** spending in year t,
- **$MILMOVE_{tlg}$** portion of **$MILPCS_{lg}$** spending in year t,
- **$SHIP_{tlg}$** portion of **$FREIGHT_{lg}$** spending in year t.

4. Model Formulation

Decision variables are in **BOLDFACE.**
Binary variables are in ***ITALICS.***

MAXIMIZE NPV of Total Savings

$$\sum_{t=6}^{20}\sum_{l\in L}(\mathrm{RECSAV}_l*\tfrac{1}{(1+r)^t})-\sum_{t=1}^{3}\sum_{l\in L}(\mathrm{RETIR}_l*\tfrac{1}{(1+r)^t})+(\sum_{l\in L}\mathrm{CONSAV}_l-\sum_{g\in G}\mathrm{LAND}_g)*\tfrac{1}{(1+r)}$$
$$+\sum_{t=1}^{5}\sum_{l\in L}((\tfrac{1}{4}\mathrm{RECSAV}_l)(2*\boldsymbol{\mathit{DONE}_{tl}}+\boldsymbol{\mathit{1THIRD}_{tl}}+\boldsymbol{\mathit{2THIRD}_{tl}})-\mathbf{UNIQ}_{tl}-\mathbf{CIVRIF}_{tl})*\tfrac{1}{(1+r)^t}$$
$$-\sum_{t=1}^{5}\sum_{l\in L}\sum_{g\in G_l}(\mathbf{SHIP}_{tlg}+\mathbf{CIVMOVE}_{tlg}+\mathbf{MILMOVE}_{tlg})*\tfrac{1}{(1+r)^t}$$
$$-\sum_{t=1}^{5}\sum_{g\in G}((\mathbf{CONSTR}_{tg}+\mathbf{HIRE}_{tg})*\tfrac{1}{(1+r)^t})-\sum_{t=1}^{5}(\mathbf{DEV}_t*\mathrm{DEV\_PEN})$$

SUBJECT TO CONSTRAINTS:

(1)

$$\sum_{l\in L}(\mathrm{RETIR}_l - \mathrm{CONSAV}_l - \tfrac{1}{4}\mathrm{RECSAV}_l(2{*}\boldsymbol{DONE_{tl}} + \boldsymbol{1THIRD_{tl}} + \boldsymbol{2THIRD_{tl}}) + \mathbf{UNIQ_{tl}} + \mathbf{CIVRIF_{tl}}) + \sum_{g\in G}(\mathbf{CONSTR_{tg}} + \mathbf{HIRE_{tg}} + \mathrm{LAND}_g)$$
$$+ \sum_{l\in L}\sum_{g\in G_l}(\mathbf{SHIP_{tlg}} + \mathbf{CIVMOVE_{tlg}} + \mathbf{MILMOVE_{tlg}}) \le \mathrm{WEDGE}_t + \mathbf{DEV_t}$$

$$\forall t \le 5$$

note: the "CONSAV_l" and "LAND_g" terms apply only for t=1;
the "RETIR_l" term applies only for t = 1, 2, 3.

(2)

(a) $$\frac{\sum_{t=1}^{t'}\mathbf{CIVRIF_{tl}}}{\mathrm{SEVPAY}_l} + \frac{\sum_{t=1}^{t'}\mathrm{UNIQ}_{tl}}{\mathrm{UNIQCOST}_l} + \frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{CIVMOVE_{tlg}}}{\sum_{g\in G_l}\mathrm{CIVPCS}_{lg}} + \frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{CONSTR_{tg}}}{\sum_{g\in G_l}\mathrm{MILCON}_g} + \frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{HIRE_{tg}}}{\sum_{g\in G_l}\mathrm{NEWHIRE}_g} + \frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{SHIP_{tlg}}}{\sum_{g\in G_l}\mathrm{FREIGHT}_{lg}} \ge 6{*}\boldsymbol{DONE_{t'l}}$$

$$\forall t' \le 5,\ \ l\in L$$

(b) $$\frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{MILMOVE_{tlg}}}{\sum_{g\in G_l}\mathrm{MILPCS}_{lg}} \ge .54{*}\boldsymbol{DONE_{t'l}} \quad \forall t' \le 5,\ l\in L$$

(3)

(a) $$\sum_{t=1}^{5}\mathbf{CIVMOVE_{tlg}} \le \mathrm{CIVPCS}_{lg}$$
$$\forall (l\in L,\ g\in G_l)$$

(d) $$\sum_{t=1}^{5}\mathbf{HIRE_{tg}} \le \mathrm{NEWHIRE}_g$$
$$\forall g\in G$$

(b) $$\sum_{t=1}^{5}\mathbf{CONSTR_{tg}} \le \mathrm{MILCON}_g$$
$$\forall g\in G$$

(e) $$\sum_{t=1}^{5}\mathbf{MILMOVE_{tlg}} \le .54{*}\mathrm{MILPCS}_{lg}$$
$$\forall (l\in L,\ g\in G_l)$$

(c) $\sum_{t=1}^{5}\mathbf{UNIQ}_{tl} \le \text{UNIQCOST}_l \quad \forall l \in L$

(f) $\sum_{t=1}^{5}\mathbf{SHIP}_{tlg} \le \text{FREIGHT}_{lg} \quad \forall (l \in L,\ g \in G_l)$

(4)

(a)
$$\frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{CIVMOVE}_{tlg}}{\sum_{g\in G_l}\text{CIVPCS}_{lg}} \ge \tfrac{1}{3} * \boldsymbol{\mathit{1THIRD}}_{t'} \qquad \forall t' \le 5,\ l \in L$$

(b)
$$\frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{MILMOVE}_{tlg}}{\sum_{g\in G_l}\text{MILPCS}_{lg}} \ge .18 * \boldsymbol{\mathit{1THIRD}}_{t'} \qquad \forall t' \le 5,\ l \in L$$

(c)
$$\frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{CIVMOVE}_{tlg}}{\sum_{g\in G_l}\text{CIVPCS}_{lg}} \ge \tfrac{2}{3} * \boldsymbol{\mathit{2THIRD}}_{t'} \qquad \forall t' \le 5,\ l \in L$$

(d)
$$\frac{\sum_{t=1}^{t'}\sum_{g\in G_l}\mathbf{MILMOVE}_{tlg}}{\sum_{g\in G_l}\text{MILPCS}_{lg}} \ge .36 * \boldsymbol{\mathit{2THIRD}}_{t'} \qquad \forall t' \le 5,\ l \in L$$

(5)

$$\sum_{t=1}^{t'}\mathbf{CIVRIF}_{tl} = \text{SEVPAY}_l * \boldsymbol{\mathit{DONE}}_{t'} \qquad \forall t' \le 5,\ l \in L$$

(6)

(a)
$$\frac{\sum_{t=1}^{t'}\sum_{l\in L_g}(\mathbf{CIVMOVE}_{tlg} + \mathbf{MILMOVE}_{tlg})}{\sum_{l\in L_g}(\text{CIVPCS}_{lg} + \text{MILPCS}_{lg})} \le \text{REQ}_g + (1-\text{REQ}_g) * \frac{\sum_{t=3}^{t'}\mathbf{CONSTR}_{(t-2)g}}{\text{MILCON}_g}$$

$$\forall t' \le 5,\ g \in G \ \text{ s.t. } \text{MILCON}_g > 0$$

$$\text{(b)}\ \frac{\sum_{t=1}^{t'} (\mathbf{CIVMOVE}_{tlg} + \mathbf{MILMOVE}_{tlg})}{\text{CIVPCS}_{lg} + \text{MILPCS}_{lg}} \le \frac{\sum_{t=1}^{t'} \mathbf{SHIP}_{tlg}}{\text{FREIGHT}_{lg}} \qquad \forall\, t' \le 5, (l \in L,\ g \in G_l)$$

$$\text{(c)}\ \frac{\sum_{t=1}^{t'} \sum_{l \in L_g} (\mathbf{CIVMOVE}_{tlg} + \mathbf{MILMOVE}_{tlg})}{\sum_{l \in L_g} (\text{CIVPCS}_{lg} + \text{MILPCS}_{lg})} \le \frac{\sum_{t=1}^{t'} \mathbf{HIRE}_{tg}}{\text{NEWHIRE}_g}$$

$$\forall\, t' \le 5,\ g \in G \text{ s.t. } \text{NEWHIRE}_g > 0$$

The objective function seeks to maximize the NPV of the total savings achieved by a specific BRAC scenario over a 20 year period by taking into account both the one-time costs / savings and the long term recurrent savings generated by the closure actions. Note that no variable terms appear in the entire first line of the objective function. The value of this line is a constant and it is only included in the formulation so that the optimal objective function value will be consistent with COBRA output.

Constraint set **(1)** ensures that net expenditures in a given year do not exceed the available budget for that year. The elastic variable $\mathbf{DEV}_t$ is included to allow the analysis of a scenario whose budgetary constraints would have otherwise led to an infeasible solution.

Constraint set **(2)** ensures that a particular BRAC action is not complete until all the transition actions which generate one-time costs are complete. Constraint **(2b)** takes into account the percentage of the military population which would rotate regardless of any BRAC action in a given year.

Constraint set **(3)** ensures that the cumulative total for each transition action captured by a decision variable does not exceed requirements.

Constraint set **(4)** turns on the appropriate indicator variables to ensure that the applicable portion of recurrent savings is realized in years when a sufficient number of personnel have been moved off a particular post.

Constraint set **(5)** ensures that all civilian reduction-in-force actions occur in the last year of the transition period for each BRAC action.

Finally, constraint set **(6)** represents "linking constraints" which ensure that the model does not try to perform an action before any logical prerequisites have been completed. Constraint **(6a)** ensures that the cumulative percentage of all personnel moved onto a particular post does not exceed the cumulative percentage of required military construction completed at that post. This constraint takes into account the assumption that construction must be paid for in year (t-2) in order to be complete in year t. Similarly, constraints **(6b)** and **(6c)** link the total percentage of personnel moved onto a post to the percentage of equipment shipped to the post and the percentage of required support personnel hired at the post.

The formulation of this model captures all the essential costs and savings considered by COBRA. All model inputs are consistent with COBRA inputs to avoid generating any new data collection requirements. In the next chapter, actual BRAC 93 data are used to demonstrate the applicability of the model and an expanded data set is used to demonstrate its flexibility with respect to various budget levels.

IV. COMPUTATIONAL EXPERIENCE

A. INTRODUCTION

This chapter demonstrates the capabilities of the model formulated in Chapter III using two test cases. The first test case uses actual BRAC 93 data to develop an optimal schedule for a scenario involving 5 losing posts and 9 gaining posts. The NPV of the optimal schedule developed by the model is compared to the NPV of the manual schedule actually developed by TABS during its COBRA analysis of the same scenario. The second test case uses an expanded hypothetical data set to develop an optimal schedule for a BRAC scenario involving 20 losing posts and 15 gaining posts. This is more than twice the maximum number of installations (15 total) that COBRA can consider for any one scenario [Richardson, 93]. The flexibility of the model is then demonstrated by conducting a budget sensitivity analysis on this data set.

For both test cases, The General Algebraic Modeling System (GAMS) is used to generate the model [Brooke, 88], and XA is used to solve the integer linear program [Byer, 92]. The first test case generated 396 variables, 70 binary variables, and 369 constraints; the model reached an optimal solution on a 486/66 personal computer in 4 seconds. The second test case generated 986 variables, 280 binary variables, and 1144 constraints; all excursions reached a solution within 5% of optimality in under 1.25 minutes. An optimal solution for all excursions was generated in under 1 hour.

B. AN ACTUAL BRAC 93 SCENARIO

The first test case scenario involves 5 losing posts and 10 gaining posts. The actual closures and realignments are summarized in the following list.

1. Realign Toole Army Depot, UT (L1) to a depot activity under the command and control of Red River Army Depot, TX (G1). Reassign excess personnel to vacant positions throughout the Army (G2).

2. Disestablish the Belvoir Research Development and Engineering Center, VA (L2). Realign the supply, bridging, counter mobility, water purification, and fuel business areas to Detroit Arsenal, MI (G3).

3. Realign the Sixth US Army Headquarters from the Presidio of San Francisco, CA (L3) to Moffet Naval Air Station, CA (G4).

4. Close Vint Hill Farms Station, VA (L4). Realign the maintenance and repair function of the Intelligence Material Management Center (IMMC) to Tobyhanna Depot, PA (G5). Realign the remaining elements of IMMC to Fort Monmouth, NJ (G6). Realign the Operations Training Facility to Fort Meade, MD (G7). Realign the Intelligence and Security Command to Fort Belvoir, VA (G8).

5. Realign the Communications and Electronics Command Headquarters from Fort Monmouth, NJ (L5) to Rock Island Arsenal, IL (G9). Realign the Chaplain School to Fort Jackson, SC (G10).

The actual data required to run the model (see model formulation, Chapter II) for this scenario were provided by TABS and are summarized in Appendix A. Roll-ups of both the optimal schedule developed by the model and the manual schedule developed by TABS for this scenario are summarized in Tables 1 and 2, respectively.

In order to evaluate the performance of the model, two comparisons were made between the optimal schedule developed by the model and the manual schedule developed by TABS . First, the NPV of each schedule was computed using the model's

	MODEL SCHEDULE all costs in $M					
	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	TOTAL
CIVMOVE	29.81	0	59.64	0	0	89.45
CIVRIF	0	0	3.86	0	0	3.86
CONSTR	73.12	0	9.11	0	6.17	88.4
UNIQ	0	0	45.04	0	2.67	47.71
HIRE	0	0	0	0	0	0
MILMOVE	0.54	0	1.07	0	0	1.61
SHIP	6.72	0	15.4	0	0.58	22.7
TOTAL	110.19	0	134.12	0	9.42	253.73

Table 1. Optimal Model Schedule for BRAC 93 Scenario. The total cost of each major BRAC action is summed across all posts for each year of the transition period.

	MANUAL SCHEDULE all costs in $M					
	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	TOTAL
CIVMOVE	0	2.22	16.09	71.14	0	89.45
CIVRIF	0	1.49	1.13	1.24	0	3.86
CONSTR	5.43	82.97	0	0	0	88.4
UNIQ	0	10.61	14.36	22.74	0	47.71
HIRE	0	0	0	0	0	0
MILMOVE	0	0	0.37	1.24	0	1.61
SHIP	0	0.58	0.2	21.92	0	22.7
TOTAL	5.43	97.87	32.15	118.28	0	253.73

Table 2. Manual Schedule for BRAC 93 Scenario. The total cost of each major BRAC action is summed across all posts for each year of the transition period.

objective function and these values were compared. Then the NPV of each schedule was computed using COBRA and these values were again compared. Figure 1 summarizes the results of these two comparisons.

	NPV IN $M	
	COBRA CALC	OBJ FUNC CALC
MANUAL SCHEDULE	667.9	735.5
MODEL SCHEDULE	891.4	1035.9

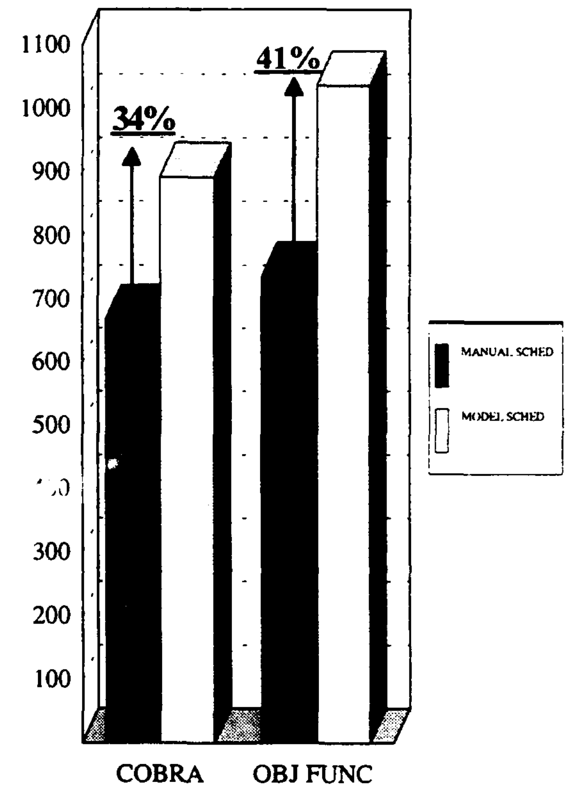

Figure 1. Comparisons of Manual and Model Schedules for BRAC 93 Scenario. The model schedule produces a 34% increase in savings ($223 M) over the manual schedule when both NPV's are calculated by COBRA.

Clearly, the optimal schedule developed by the model significantly outperforms the manual schedule developed by TABS regardless of how the NPV of the scenario is calculated. It is interesting to note that when the NPV of either schedule is calculated by both the model objective function and COBRA, the model returns a slightly higher value.

This indicates that the model tends to overestimate the NPV of a proposed scenario. This is reasonable since the model only captures those actions which produce significant one-time costs. These actions account for approximately 90% of the costs which COBRA considers when analyzing a scenario. Not considering the other 10% of the costs which COBRA takes into account, such as increased costs to the government due to Champus and Medicare when a military medical facility is closed, causes the model NPV calculation to be higher than the COBRA calculation for the same schedule of actions. However, it is important to remember that the model output of real concern to TABS is the optimal schedule itself. The TABS analyst can then program this schedule back into COBRA if a more accurate NPV calculation is required. As demonstrated above, when this approach is followed for the BRAC 93 scenario, the model's optimal schedule produces a 34% increase in savings ($223M) over the manual schedule used by TABS when both NPV's are calculated by COBRA.

C. AN EXPANDED HYPOTHETICAL BRAC SCENARIO

The second test case scenario demonstrates the robustness of the model. The scenario uses an expanded hypothetical data set to develop an optimal schedule for a realistic BRAC scenario involving 20 losing posts and 15 gaining posts. As mentioned previously, this is more than twice the maximum number of installations that COBRA can consider for any one scenario. Computational results show that the model is capable generating a schedule with a NPV within 5% of optimality in under 1.25 minutes . If necessary, an optimal schedule can be generated for this expanded data set in just under

one hour. Appendix B summarizes all the input data necessary to run the model for this scenario.

In addition to demonstrating the robustness of the model, this expanded scenario was also used to conduct a budget sensitivity analysis to show the model's flexibility in developing a schedule in light of decreasing annual budgets. The initial budget constraints for the scenario were decreased by increments of 10% to generate five different excursions for the data set. Table 3 shows the actual budget amounts used for each excursion.

ANNUAL BUDGETS IN $M					
EXCURSION #	BUDGET YR 1	BUDGET YR 2	BUDGET YR 3	BUDGET YR 4	BUDGET YR 5
1 (initial)	60	100	100	30	20
2 (10%↓)	54	90	90	27	18
3 (20%↓)	48	80	80	24	16
4 (30%↓)	42	70	70	21	14
5 (40%↓)	36	60	60	18	12

Table 3. Budget Amounts used for Sensitivity Analysis. Initial budget constraints for the scenario were decreased by increments of 10% to generate five different excursions.

The model generated a schedule for each of the five excursions listed in Table 3. Model outputs were then compared to see how the model adapted to changing budget levels. Table 4 summarizes the results of this budget sensitivity analysis.

EXCURSION #	BUDGET	NPV $M	ELASTIC VARIABLE TOTAL $M
1	INITIAL	2,948	0
2	10% ↓	2,937	0
3	20% ↓	2,916	0
4	30% ↓	NA	0.64
5	40% ↓	NA	9.7

Table 4. Budget Sensitivity Analysis. The model rearranges the schedule for BRAC actions to maintain the highest NPV possible as the budget decreases. Elastic variables indicate the additional funds necessary to accomplish all actions when the scenario becomes infeasible due to budget constraints.

The above analysis indicates that the NPV of the scenario decreases as the annual budgets for each excursion are reduced, but not by as much as one might expect. Here the model is demonstrating its flexibility by rearranging the schedule for individual BRAC actions to maintain the highest total NPV possible as budgets are reduced. Excursions 4 and 5 show how the model reacts when the given scenario becomes infeasible due to budget constraints. The model still produces a schedule for all necessary actions. The values of the elastic variables represent the additional funds necessary to actually carry this schedule out. The NPV of an excursion which has positive valued elastic variables is meaningless due to the artificial penalty cost imposed by the model for using the elastic budget amounts. However, when the additional funds indicated by the elastic variables are added to the initial budget amounts for the excursion, the model will produce a NPV for the scenario. For instance, when $640,000

is added to the initial budget amount for Year 1 of Excursion 4, the model produces a schedule identical to the original Excursion 4 schedule with a NPV of $2.8 billion and all elastic variables at 0.

D. SUMMARY OF RESULTS

The two test cases discussed in this chapter clearly demonstrate the capabilities of the model developed by this thesis. In the first test case, the optimal schedule developed by the model significantly outperformed the manual schedule developed by TABS for the same scenario. The model achieved a 34% increase in savings over the manual schedule using actual BRAC 93 data when both NPV's were calculated by COBRA. The second test case demonstrates both the robustness and versatility of the model. The model was able to produce a schedule for a scenario with more than twice the maximum number of posts that COBRA can consider in under 1.25 minutes on a 486/66 personal computer. This test case also demonstrates the usefulness of the model in determining how sensitive a scenario is to budget reductions, allowing for rapid "what if" assessments.

The next chapter discusses possible uses of the model and areas for future enhancements.

V. CONCLUSIONS

A. POSSIBLE USES OF THE MODEL

This thesis developed an optimization model to assist TABS schedule BRAC actions to attain maximum total savings. The model achieved a 34% increase in savings over the manual schedule developed by TABS for an actual BRAC 93 scenario. Clearly, all the services could benefit by using this model to schedule approved actions for BRAC 95.

Additionally, the computational results of Chapter IV indicate that the model could be extremely useful in developing closure and realignment recommendations for BRAC 95. All the services are mandated to use COBRA during their BRAC 95 analysis. By incorporating this model into that analysis, the services would be able to rapidly determine if a set of proposed closures and realignments is in fact feasible under budgetary constraints, and if not, what the budget shortfalls are. Budget sensitivity analysis would also allow a determination as to how sensitive a proposed scenario is to budget reductions. This would be useful in the cost-benefit analysis phase of the BRAC process.

B. AREAS FOR FUTURE ENHANCEMENTS

As mentioned in Chapter IV, the model currently tends to overestimate the NPV of a proposed scenario since it does not account for approximately 10% of the costs which COBRA considers. In order for the analyst to get an accurate estimate of the NPV

of a proposed scenario, he must program the schedule generated by the model back into COBRA. This can at times be a tedious process. If an interface which parses and transfers data back and forth between COBRA and the optimization model were developed, the whole process would be streamlined and more efficient.

APPENDIX A. INPUT DATA FOR BRAC 93 SCENARIO

The following four tables contain all the necessary input data used by the model for the BRAC 93 scenario discussed in Chapter IV. All data were provided by TABS and were readily available from previously conducted COBRA runs.

	YEAR OF CLOSURE/REALIGNMENT PROCESS				
	FY 1994	FY 1995	FY 1996	FY 1997	FY1998
BUDGET (in $M)	35	113.8	123.5	26.6	23.3

Table 5. Budget Amounts by Year.

	ALL COSTS/SAVINGS IN $M				
LOSING POST	CONSAV	UNIQCOST	RECSAV	RETIR	SEVPAY
L1	9.2	17.63	51.15	0.75	2.09
L2	0	1.15	13.32	0.18	0.66
L3	35.89	2.67	-5.59	0	0
L4	9.9	8.87	19.19	0.39	0.3
L5	3.5	17.39	20.86	1.06	0.81

Table 6. Total One-time Costs for each Losing Post.

ALL COSTS IN $M			
GAINING POST	LAND	MILCON	NEWHIRE
G1	0	10.37	0
G2	0	0	0
G3	0	4.72	0
G4	0	6.17	0
G5	0	11.65	0
G6	0	28.16	0
G7	0	4.65	0
G8	0	0	0
G9	0	13.45	0
G10	0	9.23	0

Table 7. Total One-time Costs for each Gaining Post.

ALL COSTS IN $M			
REALIGNMENT	CIVPCS	FREIGHT	MILPCS
L1 to G1	19.71	21.07	0
L1 to G2	0.55	0	0.06
L2 to G3	3.93	0.03	0.01
L3 to G4	0	0.58	0
L4 to G2	1.42	0	0.27
L4 to G5	1.16	0.05	0.23
L4 to G6	13.9	0.31	0.47
L4 to G7	0	0.03	0.32
L4 to G8	0.65	0	0.09
L5 to G9	47.19	0	0.83
L5 to G10	0.94	0.63	0.75

Table 8. Total One-time Costs for each L to G Realignment.

APPENDIX B. INPUT DATA FOR EXPANDED SCENARIO

The following three tables contain all the necessary input data used by the model for all five excursions of the expanded BRAC scenario discussed in Chapter IV. The scenario uses hypothetical data for 20 losing posts and 15 gaining posts.

	ALL COSTS / SAVINGS IN $M				
LOSING POST	CONSAV	UNIQCOST	RECSAV	RETIR	SEVPAY
L1	1.2	3.63	21.15	0.75	2.09
L2	0	1.15	13.32	0.18	0.66
L3	2.89	2.67	19.59	0	0
L4	3.9	6.87	9.19	1.39	2.3
L5	3.5	3.39	20.86	1.06	0.81
L6	0	0	11.21	12.32	3.21
L7	0.23	1.75	15.02	9.75	5.57
L8	0	9.35	17	6.65	0
L9	1.2	8.23	15.99	3.7	0
L10	2.5	6.8	11.76	9.3	8.15
L11	1.34	3.75	9.52	4.89	0
L12	0	2.34	21.34	11.21	3.22
L13	2.66	0	7.78	0	0
L14	0	3.22	12.41	3.45	0.75
L15	6.55	0.33	3.55	0.66	0
L16	0	7.55	18.64	4.55	7.75
L17	1.25	6.55	14.88	9.55	7.89
L18	0	5.74	9.75	4.77	3.55
L19	0.55	8.12	16.25	5.1	0
L20	0	6.55	2.77	0.78	2.33

Table 9. Total One-time Costs for each Losing Post.

ALL COSTS IN $M			
GAINING POST	LAND	MILCON	NEWHIRE
G1	3.21	1.37	0
G2	0	3.21	2.11
G3	1.2	4.72	0.75
G4	0.85	3.17	4.33
G5	2.75	8.65	0.89
G6	0	12.16	1.55
G7	2.75	14.65	0
G8	1.75	2.75	1.25
G9	0	13.45	0
G10	0	2.23	0.45
G11	2.55	3.65	1.75
G12	0	7.12	1.02
G13	2	3.1	0
G14	0.95	2	0
G15	1.89	6.75	1.23

Table 10. Total One-time Costs for each Gaining Post.

ALL COSTS IN $M			
REALIGNMENT	CIVPCS	FREIGHT	MILPCS
L1 to G1	9.71	5.07	3.21
L2 to G1	0.55	3.75	7.06
L3 to G2	3.93	2.03	4.01
L4 to G3	2.75	4.58	8.23
L5 to G4	1.42	0	3.27
L6 to G4	3.16	5.05	4.23
L7 to G5	3.9	2.31	1.47
L8 to G5	0.95	1.75	3.32
L9 to G6	2.65	5.47	7.09
L10 to G7	12.19	7.62	8.83
L11 to G8	3.94	1.63	1.75
L12 to G8	1.25	7.88	9.55
L13 to G9	5.24	3.14	0
L14 to G9	2.75	0	2.44
L15 to G10	0	4.55	7.98
L16 to G10	7.55	5.5	2.47
L17 to G10	1.55	3.78	2.74
L18 to G11	4.74	2.1	0
L18 to G12	3.27	4.75	1.74
L19 to G13	0	1.75	2.68
L20 to G14	6.33	5.14	1.24
L20 to G15	1.45	2.88	0

Table 11. Total One-time Costs for each L to G Realignment.

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